

**Proposed Facility Modifications to Support Propulsion Systems Testing
under Simulated Space Conditions at Plum Brook Station's
Spacecraft Propulsion Research Facility (B-2)**

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ABSTRACT:

Preparing NASA's Plum Brook Station's Spacecraft Propulsion Research Facility (B-2) to support NASA's new generation of launch vehicles has raised many challenges for B-2's support staff. The facility provides a unique capability to test chemical propulsion systems/vehicles while simulating space thermal and vacuum environments. Designed and constructed in the early 1960s to support upper stage cryogenic engine/vehicle system development, the Plum Brook Station B-2 facility will require modifications to support the larger, more powerful, and more advanced engine systems for the next generation of vehicles leaving earth's orbit. Engine design improvements over the years have included large area expansion ratio nozzles, greater combustion chamber pressures, and advanced materials. Consequently, it has become necessary to determine what facility changes are required and how the facility can be adapted to support varying customers and their specific test needs. Exhaust system performance, including understanding the present facility capabilities, is the primary focus of this work. A variety of approaches and analytical tools are being employed to gain this understanding. This presentation discusses some of the challenges in applying these tools to this project and expected facility configuration to support the varying customer needs.

PROPOSED FACILITY MODIFICATIONS
TO SUPPORT PROPULSION SYSTEMS TESTING
UNDER SIMULATED SPACE CONDITIONS
AT
PLUM BROOK STATION'S
SPACECRAFT PROPULSION RESEARCH FACILITY (B-2)

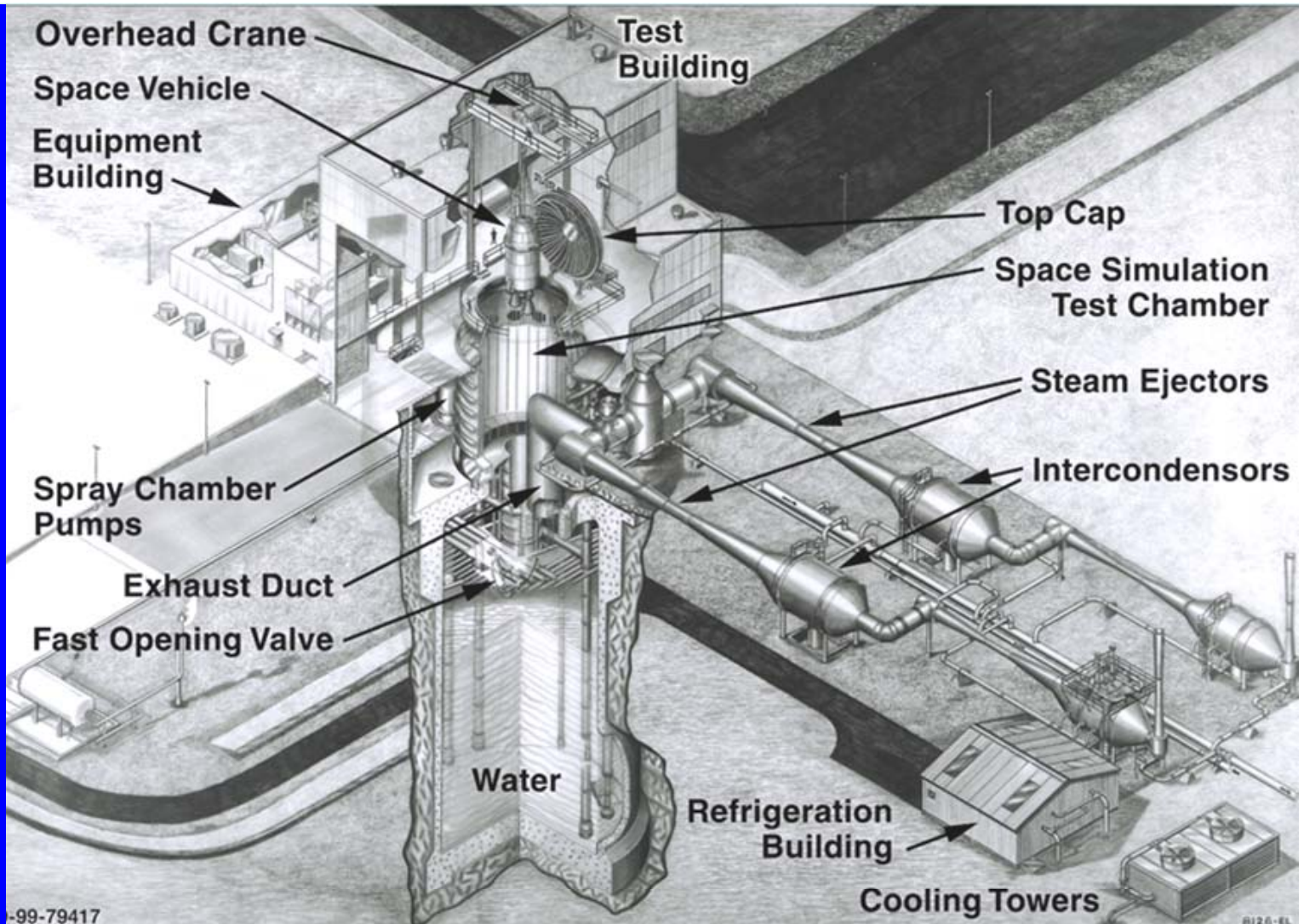


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What is the Spacecraft Propulsion Research Facility (B-2)?

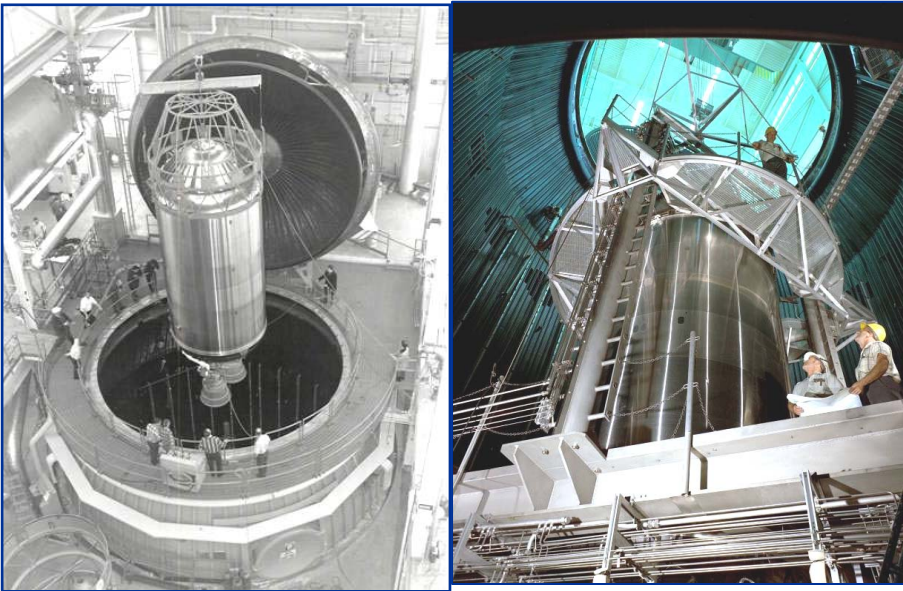
Space Environment Simulation (salient features):

- 11.6m (38 ft) diameter x 18.9m (62 ft) tall stainless steel vacuum chamber
- 10^{-5} Pa (10^{-7} torr) long duration vacuum capability
- Cryogenic LN_2 cold wall -195°C (-320°F)
- Solar thermal simulation via quartz lamp array (1400 watts/ m^2 radiant heat over 105° arc)



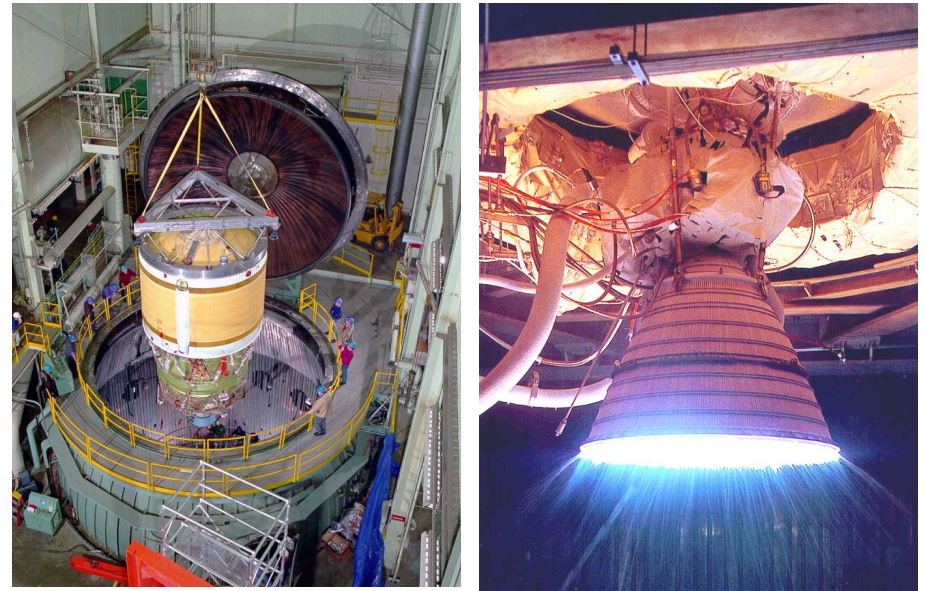
Past Test Programs

Centaur: The First Test Program



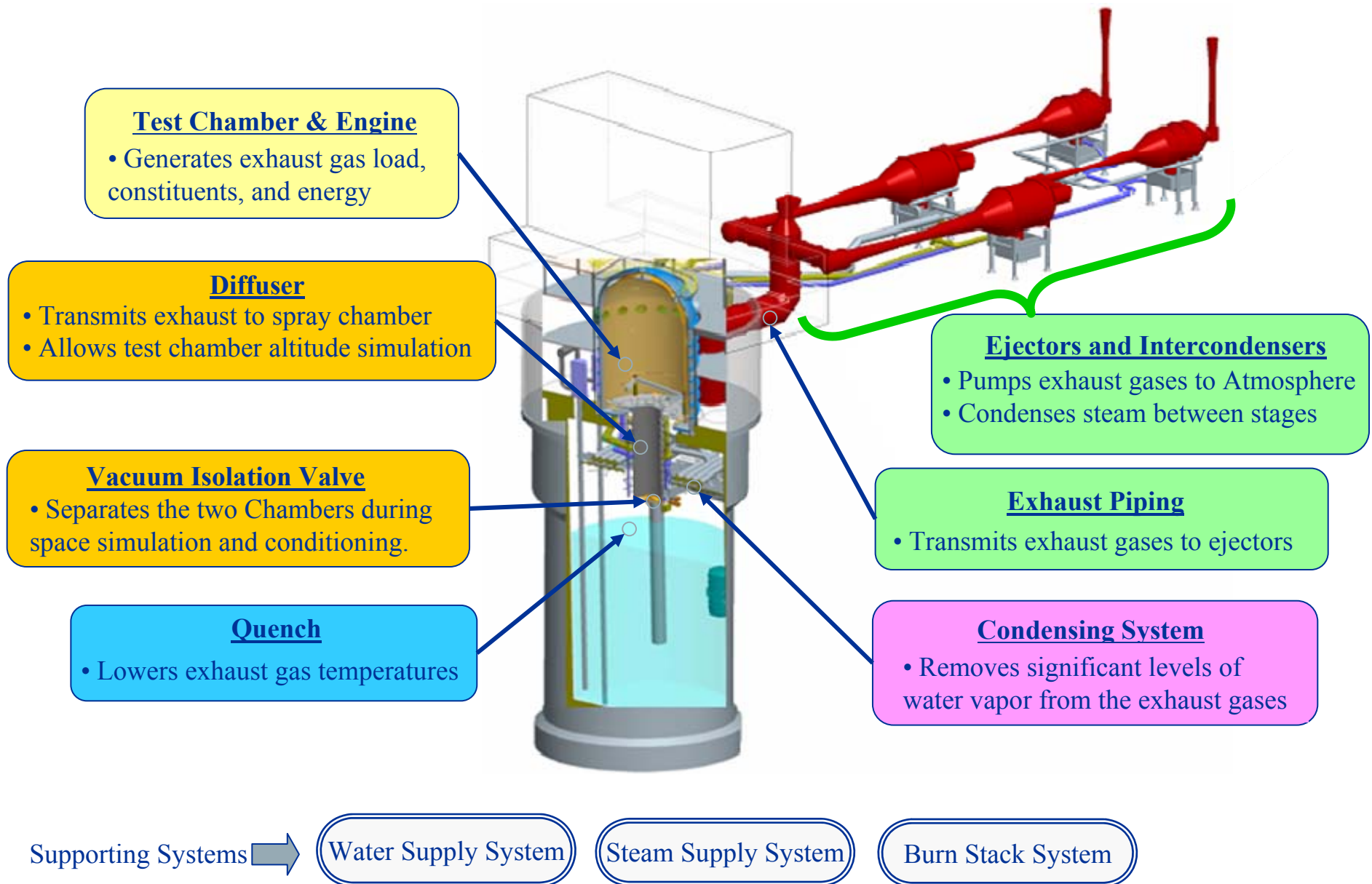
Conducted more than 100 successful hot-firings of Centaur 33,000 lbf, twin RL-10 engines at altitude and on-orbit conditions

Delta III: Latest Test Program



80 firings of current RL10B-2 engine for Delta III development and 12 firings of the Delta III upper stage

How Does B-2's Exhaust System Work?

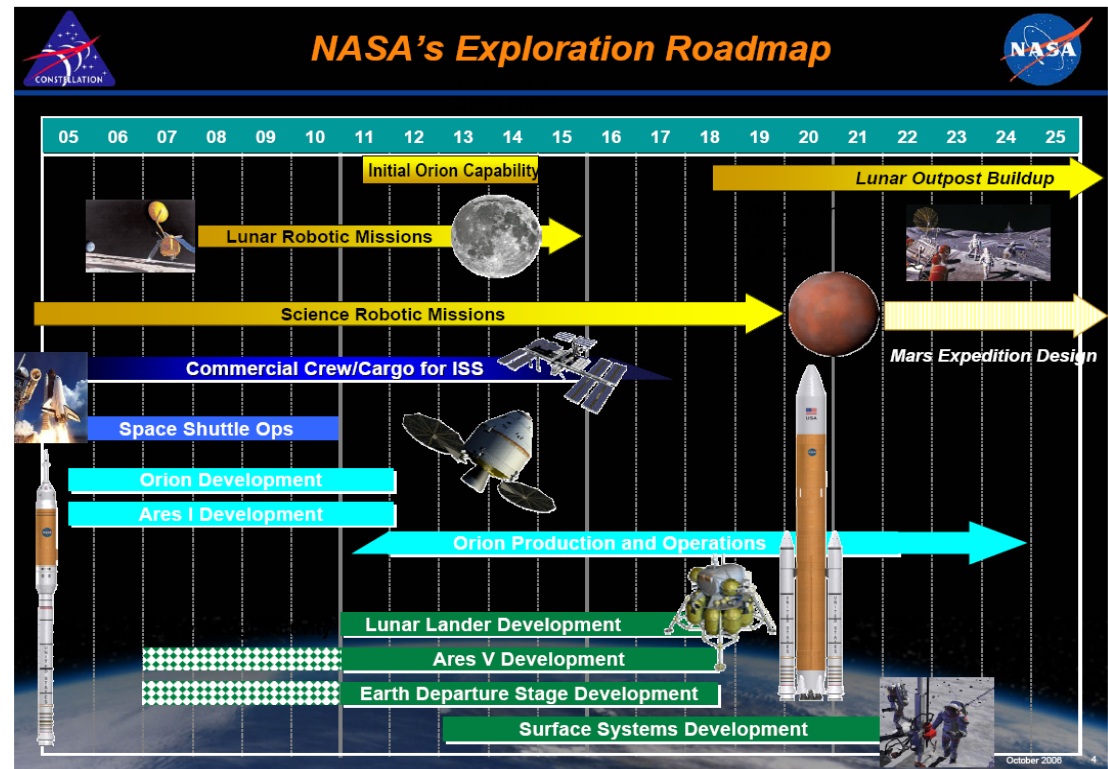


Why This Topic Now?

Propulsions systems being developed for:

- New Launch Vehicle Developments
- Lunar descent & ascent vehicles
- Mars descent & ascent vehicles

All will require various testing programs at ground facilities.



From John F. Connolly's *Constellation Program Overview*
October 2006 (avail on NASA Public Website)

Can B-2 support the necessary ground test and certification programs?

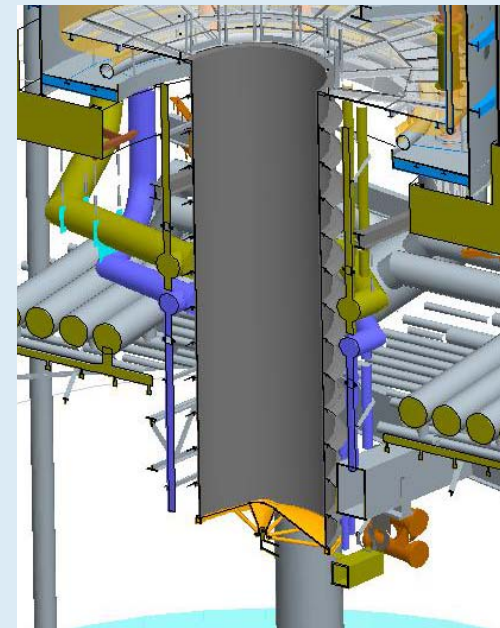
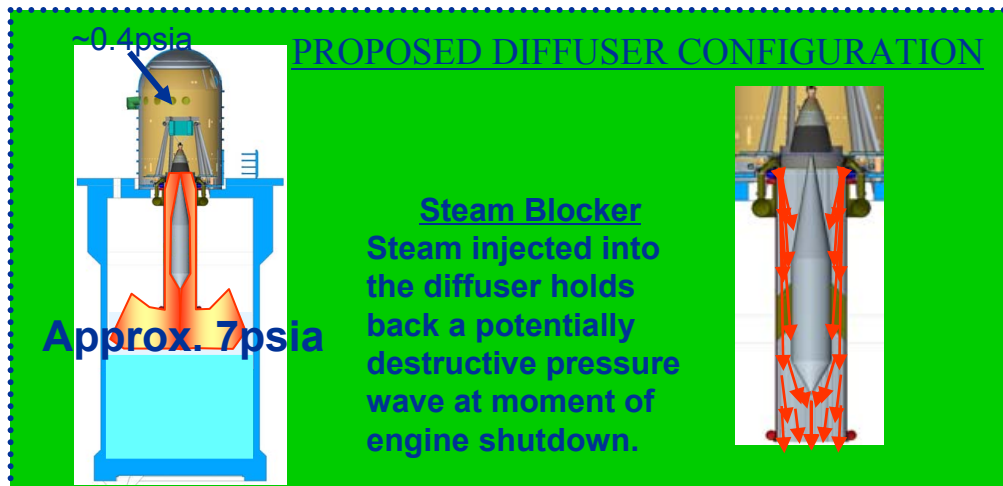
Based on the existing facility design, there two exhaust system issues that need to be addressed before a confident answer can be provided. These involve the facility diffuser immediately downstream of the engine, and the spray chamber condensing system.

Significant Issue #1 - Diffuser

Engine shutdown creates backflow – Existing diffuser allows the backflow of steam & water into the test chamber at engine shutdown. Modern engine nozzles are fragile and expensive. A soft shutdown capability must be incorporated.

One size does not fit all - Effective altitude testing requires the diffuser to match test article thrust class and test conditions. A single diffuser cannot properly serve a wide range of engines. Therefore an **interchangeable diffuser** must be incorporated.

Spray Chamber size is fixed – Diffuser shape must accommodate available space. Center Body Diffuser most effective concept for B-2.



EXISTING DIFFUSER CONFIGURATION

Significant Issue #2 - Condensing Spray Effectiveness

- ♦ **Existing Facility** – Recirculation of chilled water stored in spray chamber basin. The amount of exhaust products removed through condensation directly affects the gas load required to be removed by the ejectors.
- ♦ **Engine exhaust gas increase** – Test article thrust levels and gas loads being proposed are significantly higher than levels tested in the past (up to 10-times greater).
- ♦ **Spray Chamber performance data lacking** – The exhaust system is only lightly instrumented and available data is limited.

Result – Low confidence level in being able to predict expected performance of the facility at proposed test levels. Also makes sizing modifications somewhat risky.

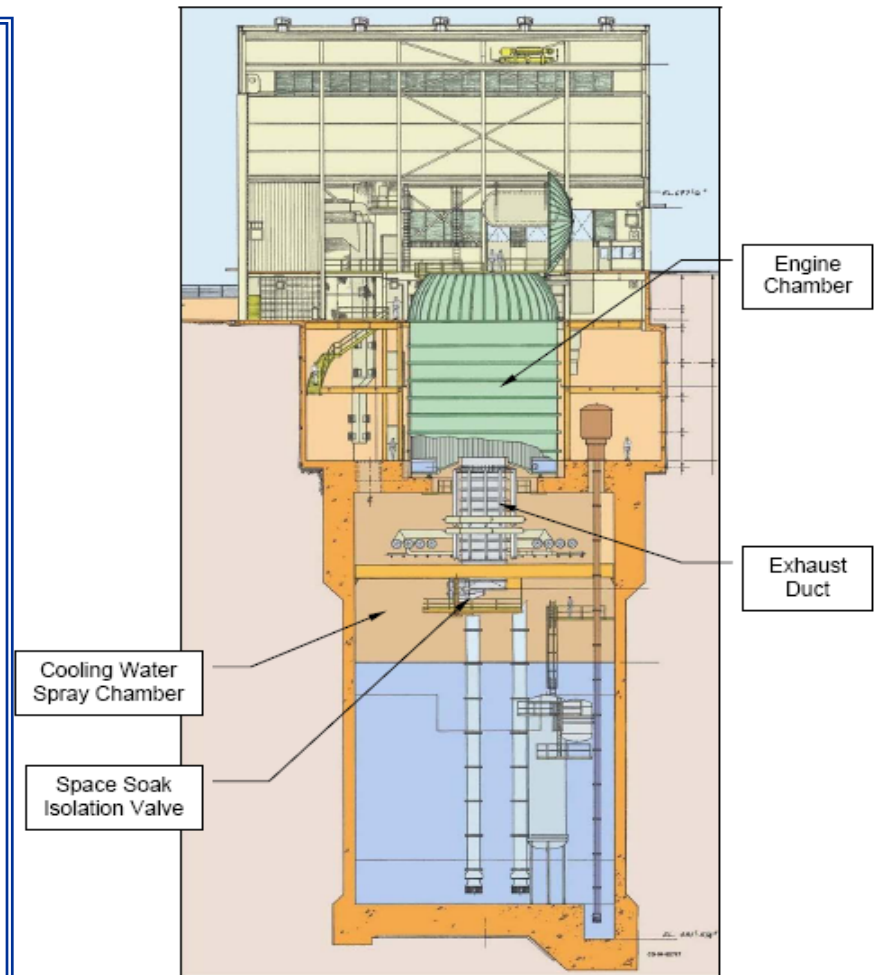


Figure 1. B-2 Spacecraft Propulsion Research Facility

Exhaust System Modeling

To answer the questions posed above and provide information for hardware sizing, design, & performance; an approach utilizing the following two efforts has been employed:

1. **Diffuser Scale Model Cold Flow Testing** – Perform testing on a scale model of a proposed center body diffuser concept to identify expected performance of the steam blocker concept for various steam injection configurations.
2. **System Level Analytical Model** - Produce an Excel based math model to closely predict performance of the exhaust system when various engines are under test.

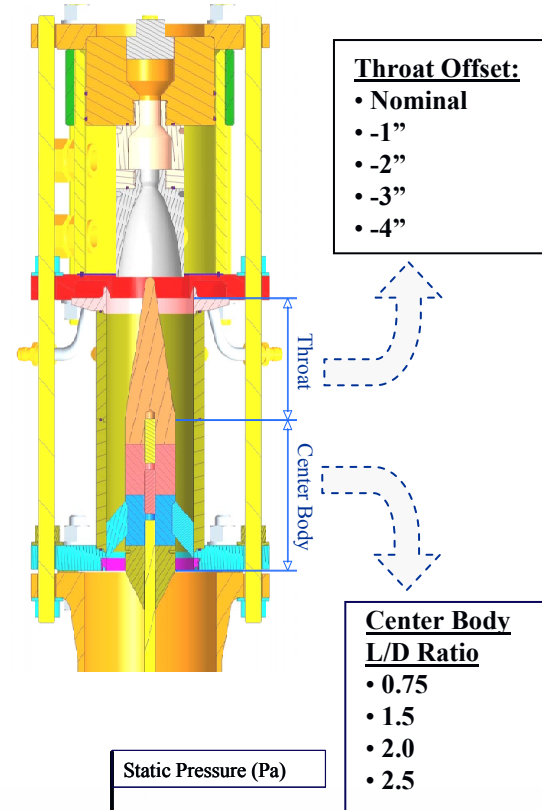
Diffuser Scale Model Cold Flow Testing

Test Setup

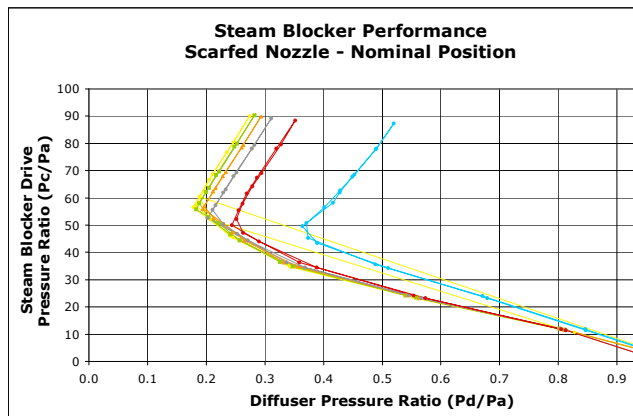


Purpose:

- Identify most appropriate configuration
- Develop expected performance for steam blocker



Typical Test Data Output



Calculated Secondary Mass Flow

Static Pressure (P_a)

P_d

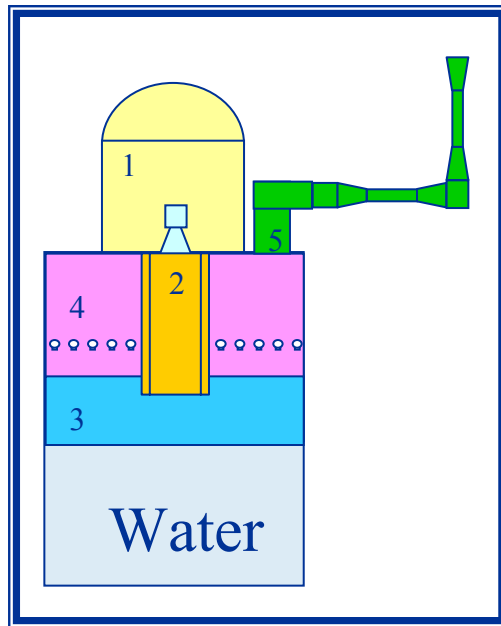
P_a

Static Pressure (P_d)

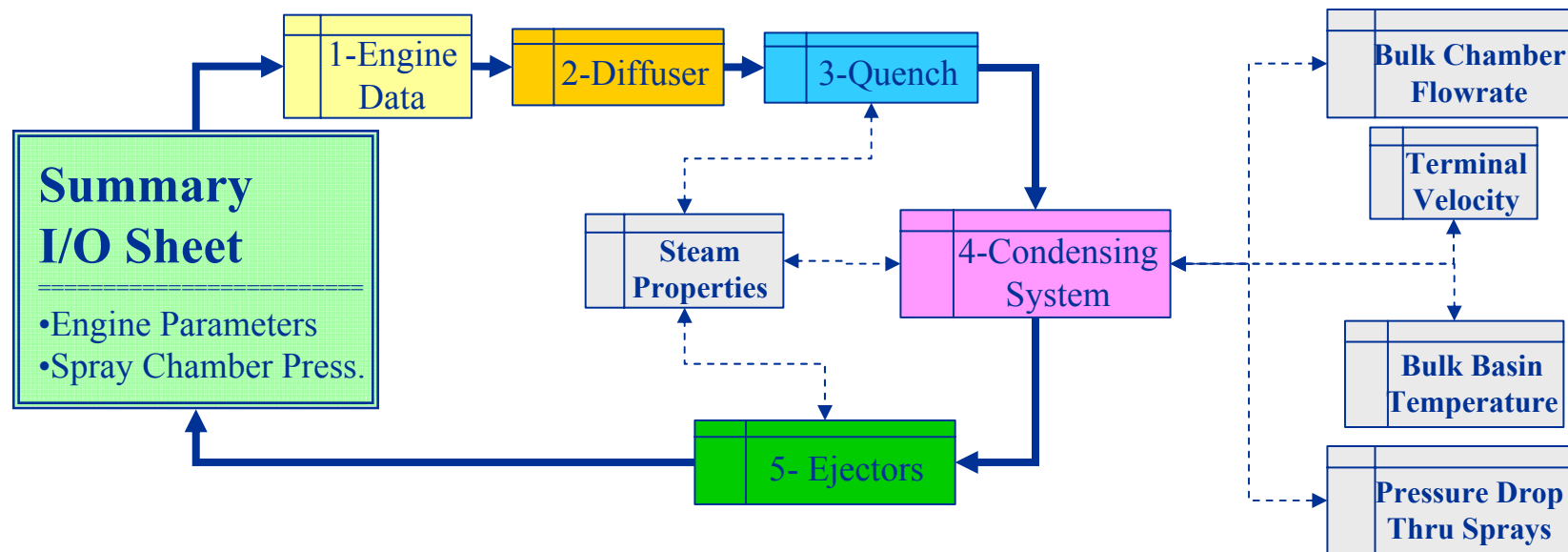
P_c

Steam Blocker
Temperature
Total Pressure (P_c)

Initial Excel Spreadsheet (System Level Analytical Model)



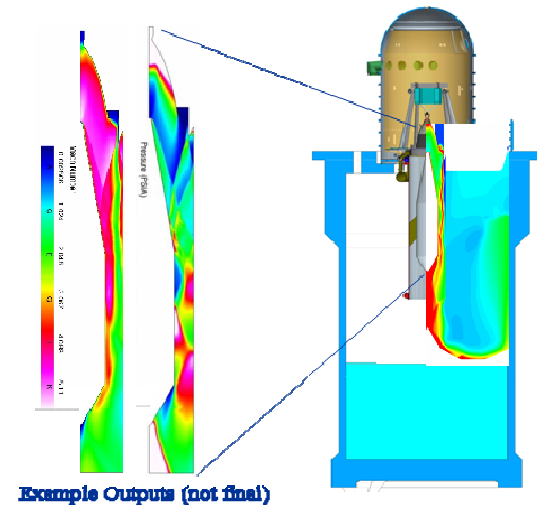
Test Cell Engine	Diffuser	Quench	Condensing System	Ejector System
<u>Inputs</u>	<u>Added Inputs</u>	<u>Added Inputs</u>	<u>Added Inputs</u>	<u>Added Inputs</u>
- Pc, O/F Ratio - Massflow	- Press. - Soft S.D. (y/n)	- Quench Water Prop's	- Spray Water Prop's	- Cooling Water Prop's
<u>Outputs</u>	<u>Outputs</u>	<u>Outputs</u>	<u>Outputs</u>	<u>Outputs</u>
- Exh. Prop's - Heat Load	- Steam Req'd - Fluid Prop's - Heat Load	- Fluid Prop's - Delta Press.	- Fluid Prop's - Delta Press.	- Press at Ejector Inlet - Delta Press.



System Modeling Updates

Modeling the condensing system became a particular challenge:

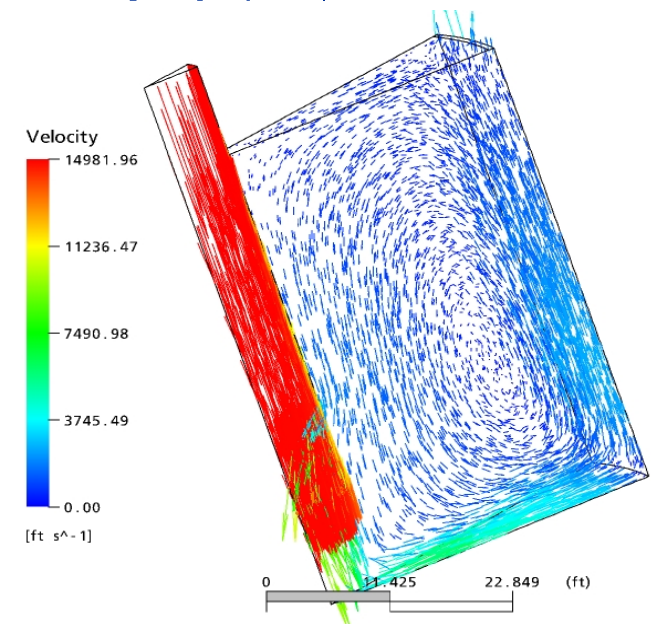
- High Gas Velocities
- Swirl and re-circulation zones of gases
- Uncertainty in quench mechanism (e.g. pool impingement, local effects at diffuser exit)
- Water droplet diameters from spray nozzles & their size distribution not verified.
- Condensing in presence of non-condensable hydrogen



A more in-depth effort is needed.

Added Modeling Efforts

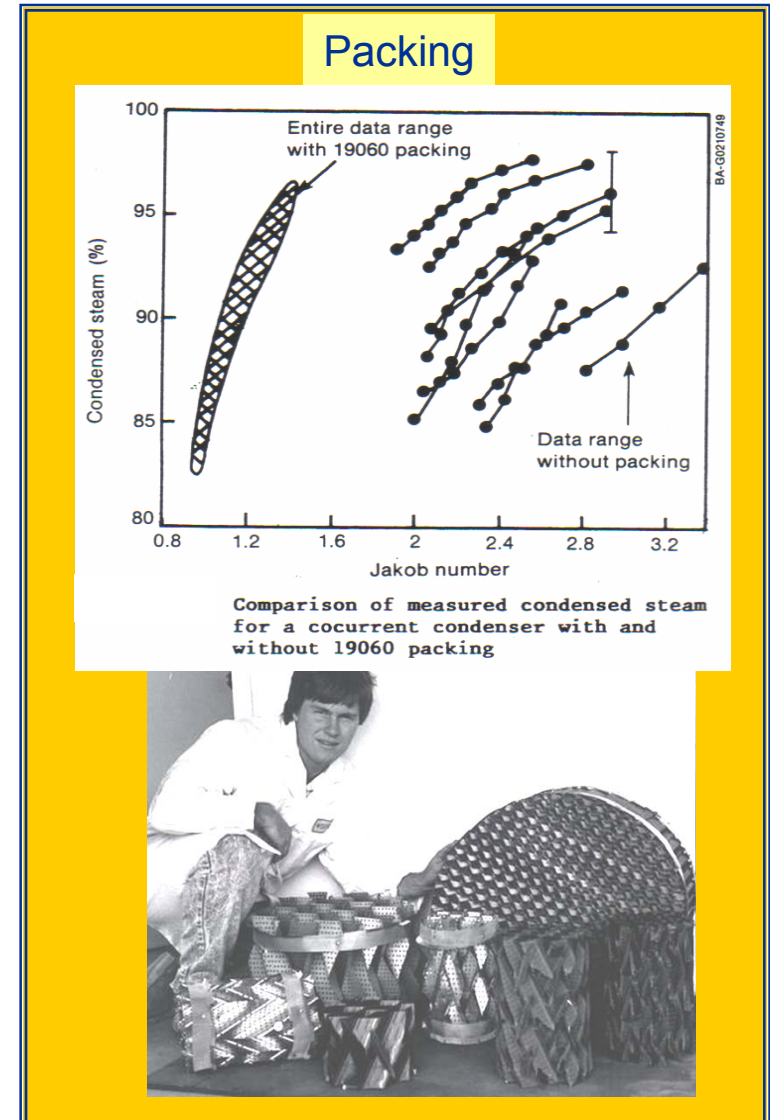
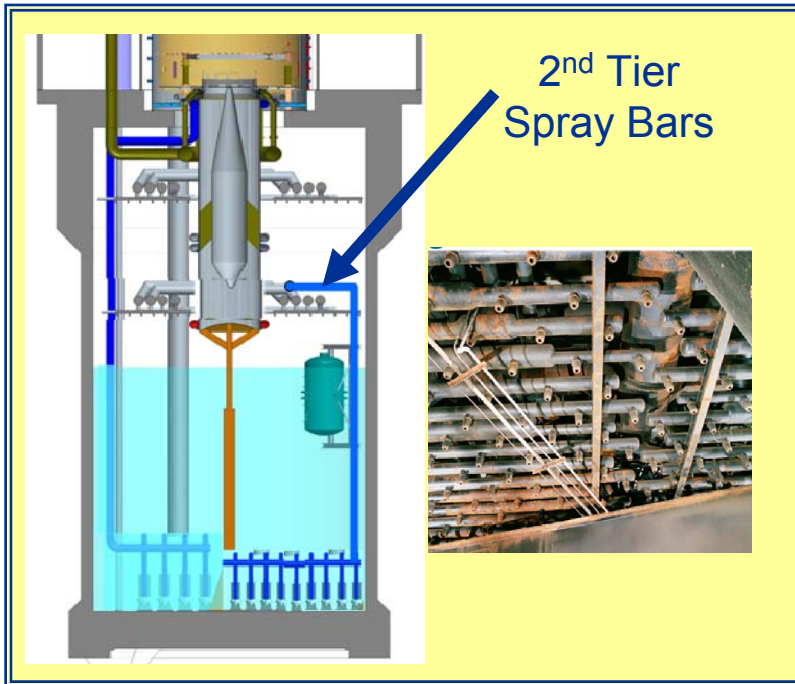
- 1-D Physics based Model
- CFD Model of Spray Chamber Performance Expectations
- CFD Model of Exhaust Diffuser Performance Expectation



Condensing System Options

Some design options being investigated for the condensing system:

- Addition of Packing inside the spray chamber to improve the effectiveness of the existing cooling water
- Installing an external condenser
- Increase total cooling water quantity through addition of a second spray bar system



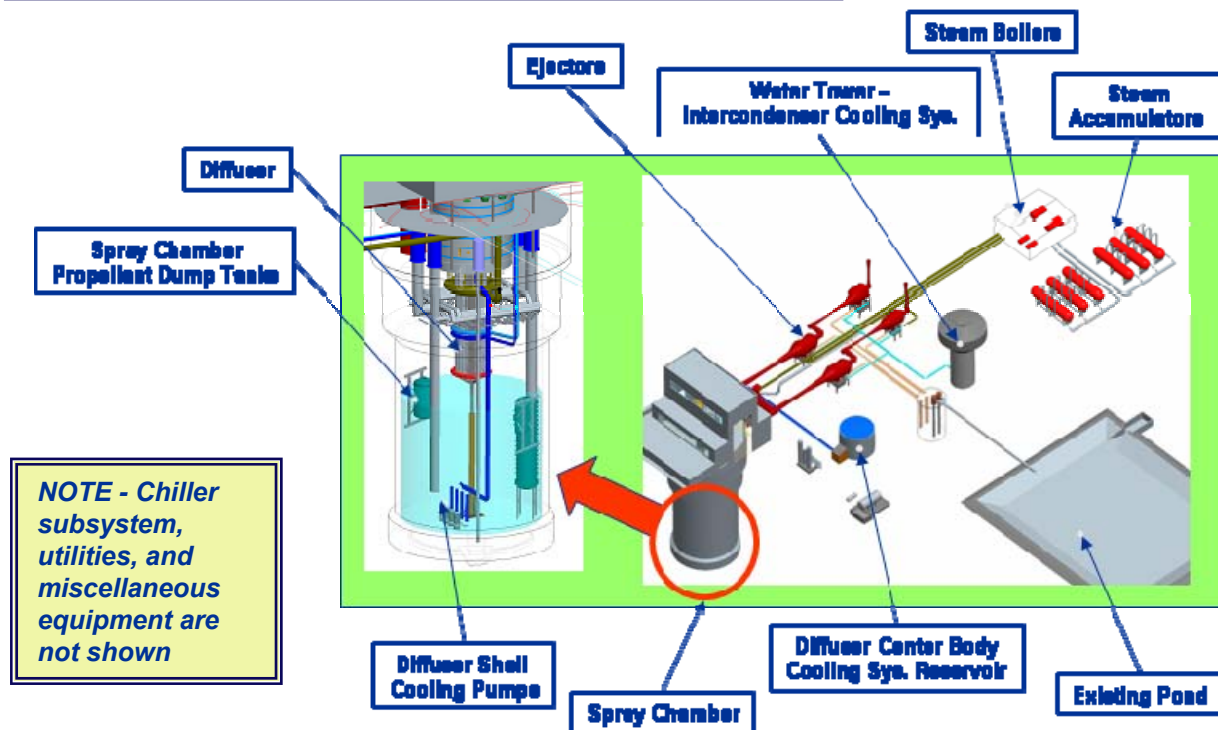
Summary

The **Exhaust System** is a key element of the propulsion capability of B-2, influencing the following significant characteristics of the facility:

- ◆ Engine Thrust Class
- ◆ Engine Firing Duration
- ◆ Altitude simulation at startup & during firing
- ◆ Exhaust system performance dynamics (impacting safety & test article survivability)

Proposed testing is beyond the limits of previous tests, thus facility performance becomes nebulous and difficult to predict.

B-2 is relying upon analytical modeling and some scale model testing to buildup a level of prediction confidence to support proposed future tests.



NOTE - This is a work in progress with several efforts underway at various levels of maturity.